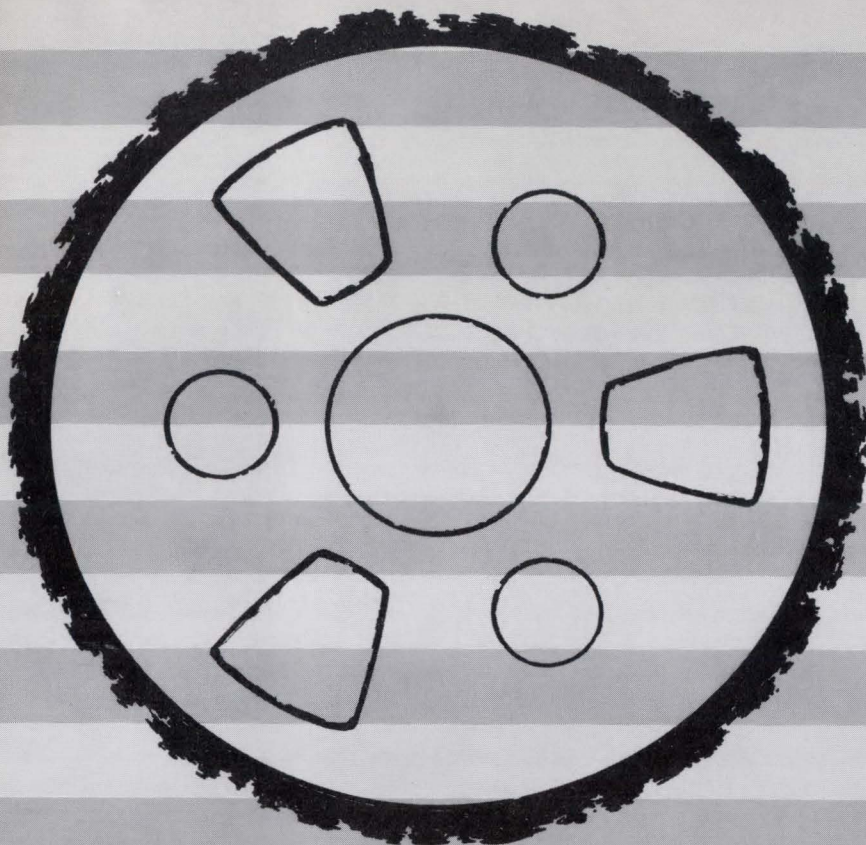


**TAPE
MEASURE
NUMBER**

2

*A Summary of Digital
Magnetic Tape Recording
Techniques and Terminology*

AMPEX CORPORATION • MAGNETIC TAPE DIVISION

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A Summary of Digital Magnetic Tape Recording Techniques and Terminology

Summary

The common terms and expressions in use in the digital computer and digital magnetic tape handler industry are defined and discussed. With the aid of suitable illustrations, methods of feeding data into logic systems and computers using digital tape handlers are considered. Problems of recording techniques are considered. Problems of recording techniques and methods for storing and transmitting adequate amounts of data in sufficiently short periods of time are delineated.

Introduction

Around the use of computers and magnetic tape equipment has grown up a dynamic terminology peculiar to the field. The following article will attempt to define and explain many of the more common terms and techniques in this relatively new field. It must be realized, however, that in an industry so young, complete standardization has not yet taken place, and new words and terms will continuously be added. Further, some groups or firms may attach a different meaning to a particular phrase or expression. So it is not intended that this be a definitive collection of computer and recording terminology, but merely a useful guide and

Magnetic recording devices play an increasingly important role in digital computation techniques. Other data-storage mediums such as punched cards or punched tapes are also used. However, magnetic tape has advantages which place it far ahead of these competitors. By far the greatest advantage is a high data-transfer rate: i.e., the speed with which information can be "read off" or "written on" the tape. An additional advantage is high-density data storage. A 2400-foot roll of one-inch-wide magnetic tape allows storage of 5×10^6 characters (or more), while 60,000 punched cards or 50,000 feet of punched paper tape are required for the same storage.

Terminology

In digital data processing, the usual mathematical system is the binary. The *bit* is the fundamental unit of the binary system and may be either 1 or 0 (zero). The *binary system* is a numbering system based on 2 (instead of 10 as in our everyday decimal system). The base of 2 was chosen because arithmetic operations can be handled with less hardware when a

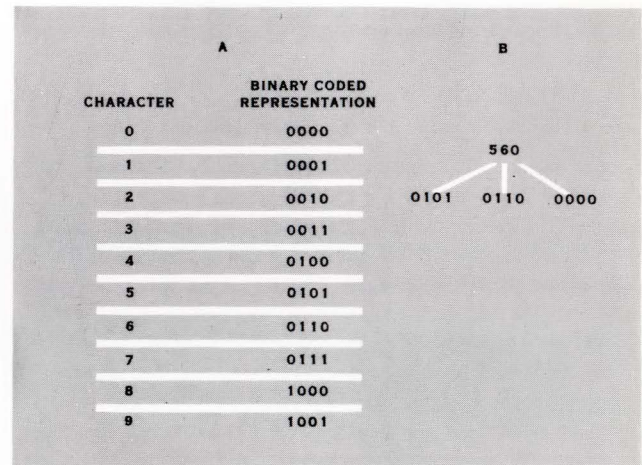


FIG. 1 BINARY-CODED DECIMAL SYSTEM

two-state system is used instead of a 10-state system such as the decimal system.

Magnetic tape lends itself very nicely to two-state operation, because it can be magnetized positively or negatively. Within the computer itself, the two states can be represented by the two conditions of a flip-flop. This fact is made use of in RZ (return to zero) or NRZ (non-return to zero) recording systems.

Binary code can be used as "pure" binary where any number is represented as powers of 2. This system is purely an arithmetic system, and is generally used in scientific computers. Binary may also be coded as indicated below: *Binary-coded decimal* systems use binary bits to represent numerical quantities. Four positions are used, with each position given a definite decimal value, from right to left, of 1, 2, 4, and 8. This coding has the advantage that a direct conversion from a decimal number to a binary representation is possible (Figure 1A). Figure 1B shows the number 560 in binary code.

An *alphanumeric code* uses coded bits in certain configurations to represent numbers, letters of the alphabet, and symbols. As an example, the IBM format uses seven tracks on a half-inch-wide tape. Coded binary is used on six tracks to represent various alphanumeric characters. These characters are constructed from the nine primary numbers and zero, 26 letters and various symbols such as periods, brackets, plus, etc. The seventh track is used for a parity check.

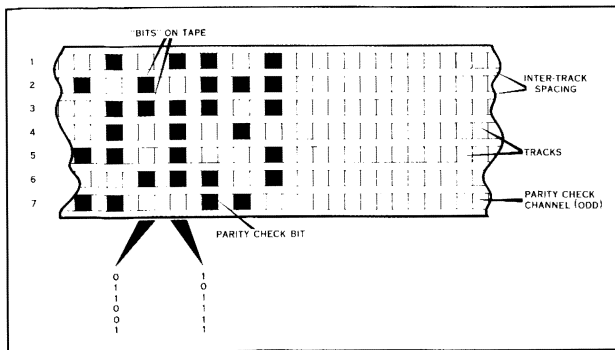


FIG. 2 TWO 6-DIGIT CHARACTERS RECORDED ON TAPE (IBM FORMAT)

A *character* is a letter, number or symbol in a coded-binary system, composed of coded bits. Characters in the IBM system are recorded across the tape, hence the extensive use of seven-track digital heads. Other computers also use coded bits recorded across the tape. The use of six tracks for character representation provides 63 combinations of bits, hence can be used to represent 63 characters. (See Figure 2 for illustration of the coding used to put information on a tape). In general, bits are used to form characters and characters are used to build up *words*. Words are combined to form *records*. A group of related records constitute a *file*.

In pure binary numerical systems, combinations of bits sometimes are called words instead of char-

acters. In a sense, word or character have similar meaning, —and that is: individual bits combined to form something of meaning other than 0 or 1.

Recording techniques

Return to bias (RB) recordings. It is possible to record bits on magnetic tape by considering magnetic saturation in one direction as zero. Ones are then represented by the opposite saturation as shown in Figure 3A. This figure represents a train of bits or pulses for 0 1 1 0 1 1 1. RB recording must be compared against a clock system in order to properly read it.

Return to zero (RZ) recording. This type of recording is illustrated in Figure 3B. You will note that in contrast to return-to-bias or non-return-to-zero recording, this method records a pulse for each and every bit, both zeros and ones. In the illustration positive pulses represent ones and negative pulses represent zeros. This form of recording has the advantage of “carrying its own clock,” since there is a pulse from the head for each and every bit.

Non-return to zero (NRZ) recording. This system also utilizes positive and negative tape saturation and is of two types: NRZ (C), meaning “change” and NRZ (M), meaning “mark.” Hence, the interpretation of the magnetic pattern on the tape is different than in RZ or RB recording. Figure 3C and 3D shows how 0 1 1 0 1 1 1 would appear, using these two systems.

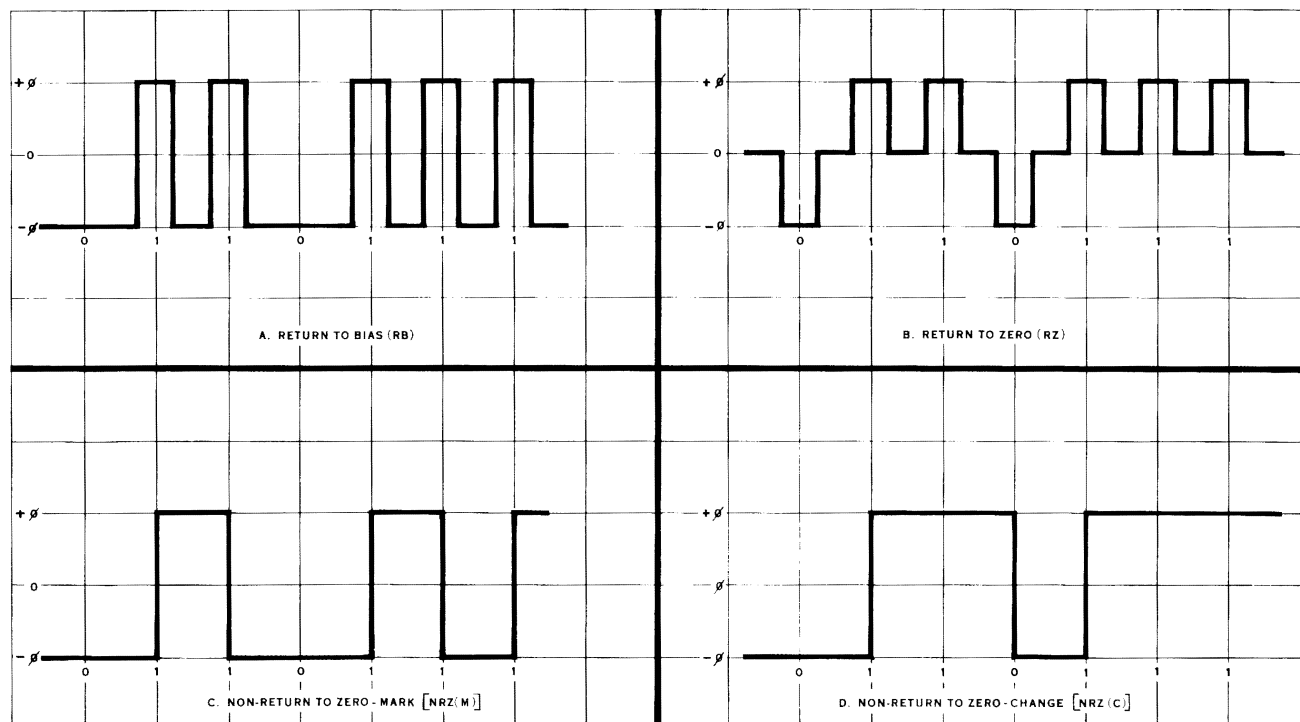


FIG. 3 RECORDING PULSE PATTERNS

The NRZ (M) system differs from RZ in that a one is represented as a *change* of magnetic state, and a zero as *no change* of state. The opposite interpretation could also be used depending upon the logic of the computer with which the recorder is being used. The NRZ (C) system also uses negative and positive saturation, but the polarity changes when it is desired to indicate a change in bits as shown in Figure 3D. It appears that in practice the NRZ (M) system offers the best reliability.

To use NRZ recording, an external clock system is required. In other words, we must "look" at the tape at regular intervals to determine if a zero or one should be read. Remember that if a change of state is interpreted as a one, no change of state is a zero. Since conventional recording heads read only a *change* of magnetic flux, no signal from the head is interpreted as a zero. In an RZ system, a pulse is read from the tape for every bit, thus providing the RZ system with its own clock.

Parity check (or redundancy check). This is a system of detecting the loss of, or picking up of, extraneous bits or pulses. A bit is recorded on the parity check track so that the number of ones across all seven tracks is odd. (An "even" parity check could be used with equal facility). If the character consists of two ones and four zeros, the parity-check bit is a one. This system can detect the loss (or addition) of an odd number of bits only. If two bits are lost, the total is still odd. It is possible to design self-checking systems using both cross and serial checking, so that complete records can be reconstructed; however the complexity of the equipment involved is great. More than 99 per cent of all errors are the result of losing a single bit and can be detected by the simple check.

Format. The configuration in which data is recorded on the tape is called the format. Proper format is necessary so that information can be fed to the computer in language it can understand and in amounts it can swallow. (This subject will be discussed in greater detail below.)

Some computers have fixed record-lengths, meaning that records are composed of a certain number of words or characters. Between each record is a gap known as the *inter-record gap*. This gap is required to compensate for the starting and stopping time of the tape transport mechanisms. The gap is generally of fixed length. Other formats are so arranged that no gap is left. In this case the computer must back up after stopping so as to get a running start on the next start command. The tape is up to speed and writing starts as soon as the end of the recorded portion passes the write head. Other computers have variable record-lengths. This means that the number of characters can differ per record.

Transfer rate and packing density

Bit packing density. The closeness with which

bits can be serially recorded on a single track is called *packing density*. The present conservative figure quoted and used throughout the industry ranges from 200 to 800 characters per inch. It is expected that the same degree of reliability can be achieved on future models at a density of 1500 characters per inch or more.

Data-transfer rate. The data-transfer rate is a function of bit packing density and tape speed.

$$R = CS$$

R—Transfer rate
C—Characters/inch
S—Tape speed, ips

Hence, it can be seen that 800 characters per inch at 150 ips yields:

$$R = (800 \times 150)$$

$$R = 120,000 \text{ characters/sec.}$$

Machines such as the TM-2 (made by Ampex), with a standard operating speed of 150 ips, can provide this high rate at a reasonable packing density. Rates of 240,000 characters per second can be achieved through use of dual character (side by side) recording on 1 inch tape.

Role of the tape recorder

Now that the basic terminology has been discussed, it will be feasible to consider the "whys" and "wherefores" of tape in the overall system. Recorders are really auxiliary equipment. They do not take part in any of the logic operations. They are slave equipment operating under the direction of the computer. Upon demand, they transfer information into the computer (input) or record data coming from the computer (output).

The tape transports must be capable of operation in both directions in order to allow the computer to search for information it needs. Reel-to-reel recorders are not true random-access devices, hence the tape must be searched for a particular *address*. An address is the part of a record which identifies it. A telephone directory is an example of a random-access device since we can go directly to the desired information. The same directory printed on a papyrus scroll would lose some of its utility unless we had a rapid means of rolling and unrolling in either direction. A roll of tape may be considered a 20th Century papyrus scroll, hence it has its limitations as far as rapid and/or random access is concerned. However, increasing tape speed results in decreased access time, since any portion of the tape can be reached more quickly at the higher speed.

$$N = \frac{\text{faster tape speed}}{\text{slower tape speed}} = \text{improvement in access time}$$

In the case of a change from 75 ips to 150 ips access time is halved, since $N = 150/75 = 2$.

If, at the same time we have an increase in the data transfer rate, the net result will be an immense increase in efficiency for this part of the computing system.

Record storage techniques

Bits of information recorded across the tape form either *digits* or characters. They are usually called digits when referring to numerical coding where these bits can represent either letters, numbers or symbols. These digits, or characters, can then be grouped to form either a *fixed word* or a *variable word*. A fixed word always consists of a definite number of characters. For example, in one computer, twelve characters form a word. Sixty of these words are then recorded along the tape to form a record of fixed length. This is then, of course, a *fixed-length record*.

Conversely, other computers use words of variable length wherein an indefinite number of characters can be used to form a word. These variable length words can then again be written serially along the tape to form a record which can be some fixed length, say 100 words as an example. This does not mean that the record occupies any set length of tape, but merely that 100 words constitute a record. The actual amount of tape utilized is a function of word length. Still other systems have variable word-lengths and variable record-lengths. In these systems, words are formed of any number of characters and any number of words can be used to form a variable-length record.

Each of the above methods has its advantages and disadvantages. For example, the fixed word, fixed record-type system *allows rewriting over an existing record* without danger of harming adjacent records. This system is also fairly good from the standpoint of tape utilization, because generally the amount of tape upon which records are written is long compared to the total length of tape utilized for interrecord gaps. In addition, fixed words make design of computers and their programming somewhat simpler, since a standard size piece of information is always used.

Variable word—variable record systems have advantages in handling certain kinds of data. It is convenient to use a system which does not have rigid restrictions imposed upon the number of characters contained in either a word or a record. Payroll records have varying amounts of information contained in them: Employees' names are not all the

same length; salaries, length of service, withholding taxes, and all the other factors which relate to payroll deductions are also not of fixed length, and therefore the content of personnel dossiers differs tremendously from individual to individual. In such circumstances, variable length words and variable length records are a distinct advantage from the standpoint of tape utilization.

If, however, many records are quite short, a large percentage of the tape can be wasted in interrecord gaps. Short records are also wasteful from the standpoint of start/stop times required between records. To overcome this problem, variable word/variable record length systems allow the lumping of many records together to form one long composite record which can be read in a single pass. (The same type of thing is sometimes done in fixed-word/fixed record-length machines. Several items may be combined in a single word by a procedure known as packing. However, more programming effort is needed in this case.)

All of the above, either fixed records or variable records, are written on the tape. Most systems generally leave interrecord gaps between the records. This interrecord gap, of course, is needed for starting and stopping the tape. Some computers, however, such as the National Cash Register Company's model 304, have minimum interrecord gaps because after stopping, the tape is backed up and repositioned. The next record written immediately follows the preceding one with a negligible gap left in between. Still another computer uses 3-inch wide tape with one set of records written in the forward direction and another set of records written in the reverse direction in the interrecord gaps, so that the tape is utilized 100%.

Groups of words within a record constitute a *field of information*. A group of records on a tape constitute a file, the same as a group of records on a given subject in the drawer of a filing cabinet constitute a file. Hence, when computer customers use terms such as file updating, master files, and grandfather files they are really talking about reels of tape and the information they contain.

Buffering systems

Various *buffering* systems are used between the input/output equipment and the arithmetic unit of a computer. These buffers can either be magnetic cores, flip-flops, or magnetic drums. Because such a terrific disparity exists between the transfer rate of information to or from a tape, and the speed of operation of the computer itself, most computers are equipped with input-output buffers. These buffers are used to overcome some of the problems associated with the relatively slow transfer rate of tape. Buffers are generally used as follows: A command

to read a certain amount of information of a specified address is given by the computer to the tape transport. The tape unit or the tape control center remembers this information and commences searching along a given tape for this particular address.

Meanwhile, the computer is free to go on its merry way doing some other operations which it may have been programmed to do. Finally, when the tape unit has found the given address, the information is read from the tape into the *input buffer* where it is stored. Upon completion of the transfer of data from the tape into the input buffer, the buffer is interrogated by the computer. The information is then transferred from the buffer into the *internal memory* of the computer and is used in further operations. Conversely, when the data is to be entered on the tape as computer output, the information is transferred from the internal memory of the computer into the *output buffer*. The information is then read from the buffer and transferred to the tape through the write system.

As short a time as five years ago, input-output buffers were not used, and the entire operation of the computer had to come to a halt during the transfer of information to or from a tape. By the use of input/output buffers, the tape equipment has in essence been shifted "off line," allowing more efficient utilization of computer time.

Buffer size, record length, and speed accuracy are in some ways interrelated. To illustrate this point, consider the NCR 304 system. It performs an operation known as copying, which is essentially that of transferring data from one file on one tape to another file on another tape. This is not like a straight duplication process where information is read directly from one tape and written on another. Data is read, transferred into the computer, operated upon, and then written on the output tape. You can readily see that speed inaccuracies in the tape transports would cause the amount of tape used to either grow or shrink, depending on whether the transfer rates were either slow or fast. If tapes recorded at 45 kilobits/second at 150 ips are played back at 145 ips, the transfer rate drops to 43.5 kilobits/second.

Speed errors on the tape are a function of mechanical tolerances in the drive system, tape dimensional changes and power line frequency variations. In order to keep the buffer a reasonable size, it is necessary to keep the speed of the tape accurate within rather narrow limits. The technique used to compensate the remaining inaccuracy is to fill the buffer one-half full and then commence reading out. If the tape is running fast with the resulting transfer rate higher than the nominal, the buffer starts to fill up slowly. If the record is too long, the buffer will eventually overflow under this condition. However, if the buffer, the record length, and the transfer or speed error are reasonably well correlated, it is possible to complete the transfer of the record

before the buffer overflows. Conversely, if the transfer rate is lower than the input rate, the buffer will gradually empty and scrape bottom if the error is too large, the buffer too small, or the record too long.

Still another system of buffering is sometimes used. In this system, when reading information into the computer, the data is transferred from the tape into an input buffer. The basic transfer rate of 45 K bits per second means that a bit will arrive every 22.2 microseconds. (Microsecond spacing = $10^3/\text{Kb rate}$). However, the buffer will be interrogated every eight microseconds and unloaded in approximately another microsecond. Hence, it is possible to read continuously from the tape into the buffer, allow the buffer to fill to capacity, dump it, and be ready to receive the next bit. Using this system, continuous tape operation is possible without regard to record length. The interrogation period plus the time to unload ($8 + 1$ microseconds = 9 microseconds) is considerably less than the bit repetition period.

Head configurations

Two basic head configurations are used for write and read operations on the tape. These are single-stack heads (combined read/write functions) or a dual-stack head operation using separate, optimized read/write head stacks. Both of these schemes have certain advantages and disadvantages. However, at the present time, single-head operation seems to be losing ground in favor of dual-stack heads because verification of data is somewhat easier with two heads than with one. In order to verify data written on the tape after using a single-stack head, it is necessary to stop after writing, reverse-scan the record, stop and drive forward again.

Two separated headstacks allow nearly simultaneous writing and reading of information. For example, standard digital dual-stack head assemblies have a separation between read gap and write gap of 0.300". At 600 characters per inch, this is approximately 180 character spacing. This spacing is sufficient that the read head can scan the tape without the need for repositioning or manipulation of the tape, and the time between write operations and readout at 150 ips is only about 2.0 milliseconds. However, it should be pointed out that this advantage is not gained without a corresponding payment being made. In this case, the payment is sometimes an increased interrecord gap length. As can be seen, after having written a record with a dual head stack configuration, the tape must continue in motion until after the end of the record has passed the read gap which is 0.300" away from the write gap. Only after the end of the record has been read can a stop command be given to the transport. Because of this, the minimum interrecord gap which can be tolerated is 0.300" + stop distance required by transport + start tolerance. Of course, it is possible through

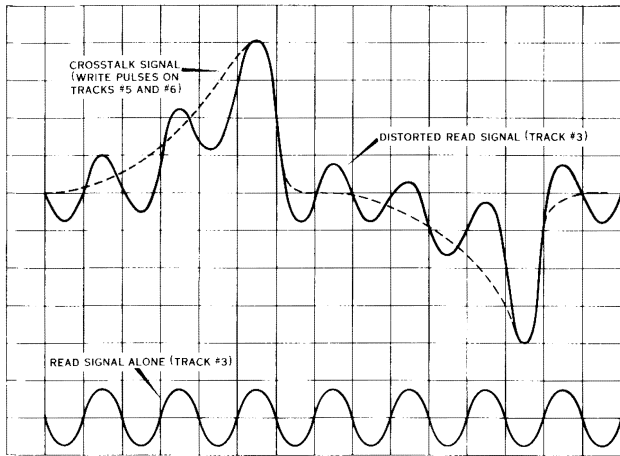


FIG. 4 CROSSTALK IN SINGLE-STACK HEAD ASSEMBLY
(DUE TO READING AND WRITING OPERATIONS)

tape manipulation to reposition the tape after stopping so that both read and write heads are parked on a previous record. The tape can then be accelerated up to running speed before reaching the record to be read or written.

The use of two separate headstacks allows simultaneous reading and writing, which is not feasible when only a single headstack is used, especially when high pulse packing densities are desired. With single headstack assemblies it is nearly impossible to interpose enough shielding between the tracks which are writing information and tracks reading information to hold crosstalk to a negligible value. Excellent coupling exists between various head cores within a single headstack and a significant amount of energy is picked up even in head windings located several tracks away from a track upon which data is being written. Large disturbances thus may be caused in adjacent or nearby read channels when writing information. Figure 4 shows how a read signal is disturbed by writing. At present this type of headstack appears to be practical only when trans-

fer rates are kept very low, in the order of 10 to 20 kilobits per second. See Figure 4 for information on the crosstalk signal during simultaneous read and write on a single headstack.

The writing function is generally controlled from the computer or external control system and will not permit writing of information on the tape unless a write signal is received. The write "gate," in the case of high speed computer use, must be capable of operation within microseconds, as all operations are done at electronic speed. Mechanical relays are not feasible in this position because too much time is required for their opening and closing.

Unrequested writing is also inhibited by interlocks on the tape transports themselves in many computer systems. These interlocks are switches which are activated either by addition or removal of some attachment to a reel of tape upon which information is to be written, and writing cannot be done unless the supply reel is properly "gimmicked" to close the write interlock. This feature safeguards pre-recorded data. Information may be written on the tape in pure binary, binary coded decimal, alphanumeric or other coding along with parity checks and, in some cases, clock signals. The use of a clock signal (for character recognition as shown later) written on the tape is not universal, however. In the event a clock signal is not recorded on the tape, other means may be used for generating a clock signal from the tape for gating purposes.

Let us follow a typical signal through a magnetic tape system. Figure 5 is a graphic representation of what happens to signals as they are fed into the input, proceed through the amplifiers, write head, tape, read head, read amplifier, and output translator. Portion A shows the type of signals which may be fed into the write amplifier and satisfactorily accepted. B shows how the signal trips a flip-flop within the write amplifier. This flip-flop then impresses a signal current upon the write head which

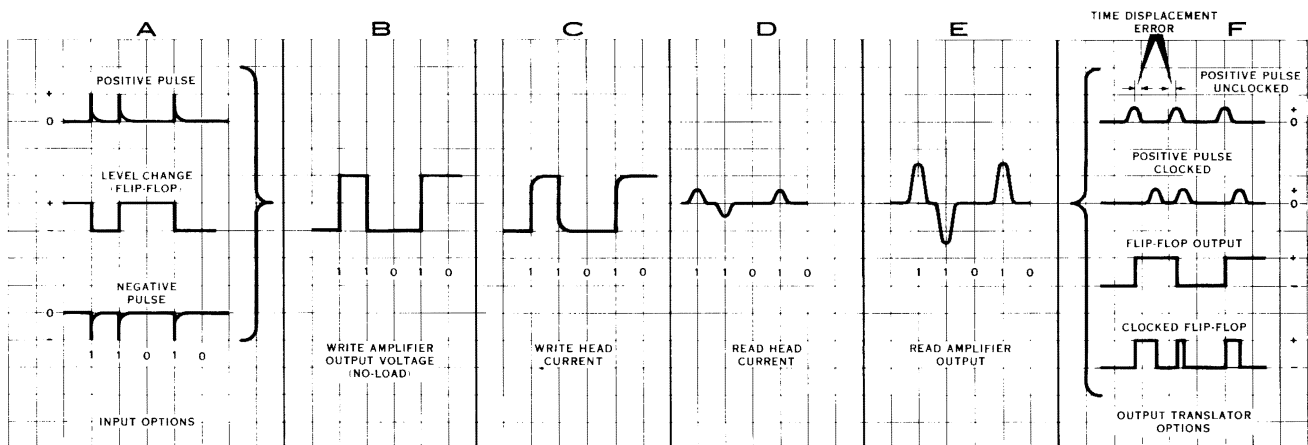


FIG. 5 TYPICAL SIGNAL WAVESHAPES THROUGH AMPLEX DIGITAL TAPE SYSTEM

is shown in Part C of the figure. This signal is then recorded on the tape as a series of transitions between plus and minus saturations. This flux pattern on the tape is differentiated by the d/dt characteristic of the read head and appears as a voltage across the head terminals. The D portion of Figure 5 shows how this signal looks coming from the read head at 300 bits per inch and 150 ips (a transfer rate of 45 kilobits per second). The signal from the head is fed into the read amplifier as in Part E where linear amplification of the head signal is accomplished.

No shaping of the signal is done at this point—however, the input is amplified to two volts peak-to-peak. The signal can then be passed on either directly to an external system where further shaping will be done, or to an output detector which can provide either pulse output or flip-flop output, either of which can be clocked or unclocked. Portion F of this figure shows the four possible outputs and the idealized wave form for each of the individual output options. The above is typical of an NRZ (Mark) recording system where each “one” is recorded as a change in flux. Other NRZ systems such as NRZ(C) have essentially unchanging wave shapes throughout the system. However, the interpretation of the output is different, since only changes from either zero

to 1 or 1 to zero are recorded, and polarity remains the same until a change is indicated.

Conclusion

We have been introduced to the major part of the common terminology that has grown up around the field of magnetic tape usage in digital logic systems. We have seen how tape recorders can be used to speed up the feeding operations of the computer. The possible areas of difficulty in the use of tape recorders and the several methods of employing the instruments so as to overcome these difficulties and obtain a high data-transfer rate are discussed.

The future of the digital magnetic tape handler in the computer field is a bright and growing one. As more and more large firms turn to handling their book-keeping and inventory procedures with the aid of computers and tape storage techniques, there should be increasing demand for more and more very high quality tape recorders. The requirements for military, scientific, and industrial use will continue to grow. The demands will be vastly in excess of those now imposed, but the rewards will be as great, and the engineering problem must and will be met to insure the continued growth of this challenging field.



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